DOCUMENT RESUME

ED 135 600 SE 021 760

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TITLE	What Research Says to the College Science Teacher.
PUB DATE	Feb 76
NOTE	30p.; Paper presented at the annual meeting of the American Association for the Advancement of Science (Boston, Massachusetts, February 22-23, 1976); Contains occasional broken type
EDRS PRICE	MF-$0.83 HC-$2.06 Plus Postage.
DESCRIPTORS	Behavioral Objectives; Chemistry; *College Science; Concept Formation; *Educational Research; *Higher Education; *Instruction; *Literature Reviews; Science Education; *Scientific Concepts
IDENTIFIERS	*Piaget (Jean)

ABSTRACT

An interpretative summary is given of educational research that has implications for college science education. The research topics include: behavioral objectives, individualized instruction, mastery learning, expository versus discovery learning, Piaget and formal thought, and proportional thinking. Specific examples taken from college-level chemistry are discussed to illustrate the problems of teaching concepts and classification. (MH)

What Research Says to the College Science Teacher

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Having recently completed the 1974 review of research in science education, I have been asked to summarize what research has to say to the college science teacher. Having begun work on the problems students have learning chemical concepts, I have asked to discuss some research that needs to be done. I will try to do both, beginning with a short, interpretative summary of the research that I have reviewed.

Objectives, Organizers, Mastery Learning, and Individualized Instruction. A systems orientation to education has influenced college teaching for the past several years. This orientation is manifested in technologies such as Audio-Tutorial instruction, the Keller Plan, and PSI. Associated with this movement are such ideas as behavioral objectives, mastery learning, advance organizers, and various forms of self-paced and/or individualized instruction. A great deal of research has been done to examine the effectiveness of these aspects of instruction. Results are seldom definitive because of the difficulty in isolating the variable of interest; still, some guiding principles emerge.

Research shows that giving lists of behavioral objectives to students sometimes leads to improved achievement but not always. Analysis of the research suggests that the issue really boils down to whether the student knows what is expected of him. If the teacher makes a point of informing the student about what is expected through verbal statements in class, frequent short quizzes, discussion of previous exams used in the course, or through tightly structured instructional materials, lists of behavioral

objectives are likely to provide redundant information and have little effect on student performance. However, if other devices are not used to inform the student of expectations in the course, the objectives (if clearly written) can be helpful. The same can probably be said about advance organizers. To the extent that an advance organizer provides information to the student concerning what is to be abstracted from a learning activity, the organizer may be effective. But if the student already has an organizational framework which serves the same purpose or if the student is provided with other means of obtaining an organizational framework, the organizer is likely to be redundant and of little value. Furthermore, it is difficult to predict when a particular introductory passage will actually serve as an organizer for a group of students. The research indicates then, that effective instruction requires some strategy to communicate expectations to the student and that new content be presented in such a way that the student can incorporate it into some meaningful conceptual framework. The most effective means to those ends seems to depend on the content being taught, the intellectual sophistication of the student and the knowledge that the student has upon entering the course.

Theoretically, instruction which is tailored to the needs of each individual and which requires the individual to master one block of material before proceeding to the next makes a great deal of sense and a number of attempts have been made to do this. The success of these strategies has not been phenomenal but neither has it been entirely discouraging. Jim Okey's (21) study of mastery learning appears to be

typical. Of the five teachers in his study who taught mathematics to students using a mastery learning strategy, one produced greater gains among the students using the mastery learning strategy. In no case did students suffer from this approach but it didn't always seem to help. We may reasonably ask, "Why?" One possible explanation is that the materials were not appropriate for many of the students; i.e., they were not tailored to the individual needs of the students. The logistical problems associated with tailoring instructional materials to each individual are enormous and it is fair to say that we are a long way from knowing how to do this on a routine basis. Most of the efforts that are made to individualize instruction place a great deal of responsibility on the student to make choices concerning the pace that he should proceed and the learning activities that he should complete. There is considerable evidence that many students are unable to handle this responsibility. Humphreys and Townsend (11) report that many students are confused and frustrated when they are given the freedom to select activities and do not achieve very much as a result. Such freedom to choose activities generally provides freedom to do nothing and poorly motivated students procrastinate more than they should. Furthermore, students who are motivated to proceed may not be capable of planning the best sequence of instructional activities. Gunter (8) reports that biology students who planned their own sequence of activities for a unit of instruction took twice as long to complete the unit as did students who followed a sequence which the instructor outlined on the basis of pretest results.

Failure of students in an individualized course to select appropriate activities may be influenced by their lack of motivation or their inability to interpret feedback that they receive. If a student is not highly motivated, he may convince himself that additional learning activities are not really necessary even though feedback from quizzes or other sources indicates that further work is called for. At least we know that less able students in an individualized course are more confident of their ability to skip materials that they "already know" than are high achievers in the course. (18, 25) We would expect the opposite.

Findings such as these suggest that we need to provide safeguards if we expect students to achieve in individualized programs. Students are helped when the units of study are kept short, when feedback is frequent, and when progress is carefully monitored. For some students, it is probably necessary for the teacher to provide considerable guidance in structuring the learning activities.

Expository vs. Discovery Learning. One of the controversies in science education over the past decade has been over the relative importance of expository and discovery learning. Weimer (24) did a critical analysis of studies that compare discovery oriented and expository instruction in the fields of math, science, language, geography, and vocational education. The studies analyzed focused on retention or transfer and the author reports that no clear evidence of a single superior method of teaching was indicated.

It is, perhaps, a measure of our naivete that so many expect some clear indication that "method A" is superior to "method B". An instructional system is complex and most variables extant in the system have been shown to affect learning under some set of conditions. We know, for example, that the personalities of both teacher and student influence learning, that the difficulty of the learning materials may interact with method of instruction, that reading level or the kind and amount of laboratory activity can influence learning, and that the quality of instructional materials is important. What we do not know is the set of conditions under which each of these variables will or will not have an influence.

Some hint of the conditions under which discovery learning may be better or worse than expository learning is found in the study by Danner (7). In his analysis it was found that the expository method of instruction was more effective when a difficult lesson on pressure was taught. Conversely, the discovery approach was more effective when an easier pendulum lesson was taught. It seems reasonable that expository presentations are better when the material to be taught is so difficult that students are unlikely to discover important relationships on their own while discovery approaches are more effective when the principles to be learned are more transparent. When it is possible for students to discover that which we want them to learn, the increased interest and motivation that may result from discovery approaches will increase the attending behavior of the student and more will be learned. However, the increased attention

of the student has little effect if the student is unable to sort the important observations from the misleading. Indeed, a more structured, expository presentation may be desirable to <u>prevent</u> the student from being distracted by observations which are irrelevant or misleading when the lesson deals with a difficult topic.

It should be kept in mind that this discussion of discovery and expository learning pertains primarily to the learning of new facts and principles. Proponents of discovery learning often argue that the primary benefit of discovery strategies is in the development of more sophisticated thought processes.

<u>Piaget and Formal Thought</u>. Most science educators are aware of Jean Piaget's description of intellectual development in terms of stages, beginning with the sensor-motor learning of the infant and culminating in formal operational thought of the adolescent. (12) Many are also aware that formal operational thought has not been acquired by a substantial number of students at the time they enter college.(6, 19, 23) Since many of the concepts and principles taught in science and mathematics require formal thought for their understanding, this situation is one of considerable concern. (10) Social pressures to enlarge the opportunities for minority groups and women in science and mathematics add to this concern because there is evidence that fewer women (16), fewer individuals of low socioeconomic status (13), and fewer individuals from minority groups (20) have developed formal operational thought than other individuals of the same age.

The implications of these fondings for college teaching are cogently described in a paper delivered by Robert Karplus at the Second Annual Convention on Personalized Instruction and paraphrased here.

"The first conclusion,. . . is that certain higher level instructional objectives will be unattainable by [students who are not formal thinkers] within the limited time available during a single course, regardless of the quality and thoroughness of the teaching aids. You therefore must consider these possibilities; (1) Aim your course primarily at [formal] students and discourage [non-formal] students through counseling and failure on early assignments; (2) Aim your course primarily at [non-formal] students and discourage [formal] students through counseling or boredom on early assignments; (3) Aim your course at a mixed student body through "basic" assignments appropriate to [non-formal] students and "advanced" assignments for extra credit for [formal] students, but without expecting developmental progress by students; (4) Provide, in addition to content objectives with their goal of mastery, supplementary activities that encourage advancement from one developmental stage to the next without requiring mastery." (14, pp 4-5)

Karplus' proposals may be reduced to two choices: (1) We may try to circumvent the problem by limiting instruction to those concepts and principles that can be understood by students who are not formal thinkers or (2) we can attempt to improve the intellectual functioning of students. As suggested earlier, many proponents of discovery learning feel that discovery teaching will abet the latter objective. Unfortunately, I know of no

strong evidence to support this contention. However, many of the techniques used in discovery teaching are similar to the procedures proposed by Karplus and his associates at AESOP to promote formal thought through self-regulation. It is possible that such strategies can be beneficial.

Since Tony Lawson is reporting on work being done to assist students in the development of formal operational thought, I wish to explore the other suggestion that I have made, namely, to circumvent the problem by limiting instruction to those concepts and principles that can be understood by students who are not formal thinkers.

First, let me emphasize the magnitude of the problems inherent in this proposal. One of the characteristics of formal thought is the ability to deal with proportional logic. This may be illustrated by the Metric Puzzle found in the AAPT materials prepared for the Workshop on Physics Teaching and the Development of Reasoning (2).

The Metric Puzzle presents the student with roadsigns like the following and asks the student to calculate the number of miles to Wahoo.

Cleveland	Wahoo
94 miles	_____ miles
152 kilometers	380 kilometers

Typical responses of formal and non-formal students are given in Table 1. Note that even though the procedures used by the formal students (designated by "A") differ, they all recognize the proportional relationship between

miles and kilometers. By contrast, the non-formal students (designated by "B") typically use some kind of difference strategy and fail to recognize the proportional relationship. Indeed, they seem to be incapable of handling proportional logic at all.

Now let us consider the implications of this problem in teaching science. Proportional logic is encountered throughout physics. Concepts such as density, velocity, acceleration, the gas laws, Hooks Law, and coefficients such as that for linear expansion all involve proportions. All of the problems in chemistry which involve mole relations are based on proportional logic. Concentrations, dissociation constants, and all rate expressions also involve porportions. Proportional logic is prevalent in common situations outside of the classroom. Comparing the cost of a 6 ounce can at 38¢ with an 8 ounce can at 52¢ requires the same kind of logic as the metric puzzle. So does the caluclation of the cost of 20 pencils when pencils sell for $13.00 a gross.* Indeed, problems which involve proportional reasoning are so pervasive that one may seriously question whether it is possible to teach science to students who are not capable of formal thought. But within certain limits, I believe that we can, providing that we are willing to teach certain students to <u>do</u> science without understanding science.

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*That such reasoning is difficult for many people is abundantly clear from the results of The National Assessment of Educational Progress which reports that less than half of 17 year olds and adults are able to solve problems of this type. (22, p 114)

Students who are not able to understand the logic of certain procedures can learn algorithms for carrying out the procedure. It is doubtful that anyone in this room really understood the logic inherent in the algorithms learned in elementary school for multiplication or division. Rather, the algorithm was learned as a rule which could be applied to get an answer to a particular kind of problem. This didn't seem to bother anyone until mathematicians became concerned that students were learning to do without ever understanding mathematics. They began to alter the mathematics program in the schools and the result has not left science teachers entirely happy. I believe that a similar situation pertains in science.

It is not clear that home economists or agriculturists or even engineers are always interested in understanding all of the logic behind the science that we teach. To a certain extent, these individuals are looking to science to provide facts and skills that can be applied to practical problems. In so far as this is the case, science teachers may be justified in teaching students to perform certain operations that they do not fully understand.

An experience at Purdue with underprepared chemistry students suggests that there are strategies that can be used to circumvent some of the problems encountered by students who are not formal thinkers. For example, by using factor-label, students who are not formal in their thinking can be taught to solve problems involving proportional logic. Factor-label is not new and it is routinely used by most science teachers

because they have found that it is easier for students than ratio and proportion. Although there are several variations used in practice, the essential strategy is to use unit factors to convert a measure in one unit to an equivalent measure expressed in different units. Using the Metric Puzzle as an example, the student is asked to look for an equality which can be used to produce a unit factor that will aid in solving the problem. After some practice with the strategy, the student is likely to see that 94 miles must be equal to 152 kilometers since both represent the distance to Cleveland. Then:

$$94 \text{ miles} = 152 \text{ kilometers}$$

$$\frac{94 \text{ mi}}{152 \text{ km}} = \frac{152 \text{ km}}{152 \text{ km}} = 1$$

The student then uses the resulting unit factor to find the equivalent of 380 km in miles.

$$380 \text{ km} \times \frac{94 \text{ mi}}{152 \text{ km}} = 235 \text{ miles}$$

Even though this algorithm presents some problems in logic for the non-formal thinker, it appears to be far less demanding than the straight forward application of ratios. If early exercises are selected so that the student can check the validity of the statement that the unit factor is indeed equal to unity, he develops faith in the generality of the algorithm and is willing to use it in situations where the validity of the unit factor is less apparent. For example, we ask students to measure some distance in both centimeters and inches so that they have concrete

evidence that the two measures used in the unit factor are indeed equivalent. Then we have them express the equality, find the unit tor, and state why it is equal to unity.

In using unit factors wi [illegible] udents, one may encounter another problem. It is common practice to work problems involving several steps without closure at the end of each logical step. For example, in calculating the number of seconds in one year, one might proceed as follows:

$$1 \text{ year} \times \frac{365 \text{ days}}{1 \text{ year}} \times \frac{24 \text{ hours}}{1 \text{ day}} \times \frac{60 \text{ min}}{1 \text{ hour}} \times \frac{60 \text{ sec}}{1 \text{ min}} = 31\ 536\ 000 \text{ sec}$$

Students who have not developed formal operational thought are not able to follow this solution. The solution makes sense only if one is able to accept that the number of days in one year will be found <u>if</u> one multiplies the years by 365; that the number of hours in one year will be obtained <u>if</u> one multiplies this result by 24; that the number of minutes in one year will be found <u>if</u> one multiplies that result by 60; that the number of seconds in one year will be found <u>if</u> the last result is multiplied by 60 once more. As the problem is presented above, these separate operations are not carried out to obtain a result and there is no closure on the problem until the end of the sequence of logical steps. Collis (3, 4, 5) has investigated the development of formal reasoning in mathematics and has found that non-formal students are not able to handle this lack of closure. As inefficient as it may appear to those of us who are comfortable with formal thought, the problem illustrated here must be worked in four separate steps with closure at the end of each logical step if non-formal

students are to be able to follow the logic.

The need for closure on the part of non-formal students has a number of implications. For example, Collis' work suggest that these s' ts are not able to perceive indicated products such as (2 x 3) as names for numbers. They first carry out the indicated operation to obtain closure and find that 2 x 3 is equal to 6. (Note that they are not saying that 2 x 3 is 6 but simply that once you carry out the operation, you get the number, 6.) In science we are virtually forced to use expressions such as 6.02×10^{23} or 1.66×10^{-24} for numbers that cannot be written conveniently in an ordinary way. But Collis' work would indicate that non-formal students perceive such expressions as indicated operations which would yield a number if they were carried out but do not see the expression as a number in itself. I wish that I could tell you how to circumvent this problem but I have yet to come up with a suitable strategy.

If we are to teach science to non-formal students by circumventing the logical problems that they encounter, we need far more information about the concepts and principles that we teach which involve such difficulties. It seems to me that we could profit from a careful analysis of concepts and principles that we teach with such a goal in mind. We have begun to do this at Purdue and I would like to describe what we have done so far.

Since concepts and principles are the essense of what we teach and since principles involve the interrelationships among concepts, it seemed reasonable to begin with an analysis of concepts. We have based our work on the Conceptual Learning and Development Model (CLD) proposed by Klausmeier

and his associates at Wisconsin (15) and have used concept analysis as proposed by Markle and Tiemann at the University of Illinois (17). Based on the CLD model and using concept analysis as a tool, we hope to sort chemical concepts into groups which present similar learning difficulties. We then hope to develop teaching strategies which circumvent these difficulties or, if this proves impossible, identify those concepts that are likely to be inaccessible to students who are not formal thinkers.

Before describing what we have done so far, it may help to point out some of the characteristics of concepts that make them difficult to learn.

1. Validity. Concepts differ in validity. For concepts in science such as mass, length, pressure, and element, there is little or no disagreement concerning the meaning of the concept label. Such concepts are said to have high validity. Other concepts such as chemical change, valence, living, and mole do not have meanings which are universally accepted by experts in the field -- or at least they do not mean the same to all science teachers. These concepts are said to have low validity. Concepts of low validity are more difficult to learn than concepts of high validity.

2. Number of relevant attributes. Concepts are defined in terms of the attributes or conditions that must hold in order for an instance to be considered an example of the concept. For example, plane figure, closed figure, and three straight sides are attributes of the concept, triangle. Although other attributes may be listed; e.g., three angles, the three given are sufficient to define the concept. Other concepts may require more or fewer attributes to define the concept. Concepts with few defining attributes are easier to learn than concepts with many defining attributes.

3. Conceptual Rule. Certain conceptual rules may govern the decision of whether an instance is or is not an example of a concept. It has been shown that conceptual rules from easiest to hardest are: conjunctive, disjunctive, conditional, and biconditional. (1)

4. Abstractness. Two considerations govern the abstractness of a concept. Concepts with few perceptible instances are more abstract than those with many perceptible instances. For example, atom, molecule, and mole are abstract because they have no perceptible instances whereas man, beaker, and heat are less abstract because they are perceptible. The abstractness of a concept is also governed by the degree to which the attributes of the concept are perceptible. For example, metal, element, compound, and mixture are all concepts with numerous perceptible instances but the attributes which govern the classification of objects as examples or non-examples are not perceptible and the concepts are abstract. The more abstract the concept, the more difficult it is to learn.

Older children find it easier to learn abstract concepts than younger children and there is reason to believe that this difference may be associated with the development of formal operational thought. One of the characteristics of formal thought is the ability to think in terms of possibilities and to reason in terms of hypothetical events which have not been experienced or can not be experienced. Concepts such as frictionless surface, ideal gas, point mass, infinity, and limit represent such hypothetical constructs which are commonly used in science but outside the rational power of non-formal students.

The four characteristics of concepts which have been listed here and which are known to influence the difficulty of learning concepts can be used as a basis for classifying science concepts. In our initial effort to develop a taxonomy of chemical concepts we have focused on concepts which name entities (as opposed to concepts which describe or modify these entities) and have used abstractness as a dimension for classification. A portion of this classification is shown as Table 2. The present scheme is tentative and will undoubtedly change but it does illustrate the rationale for our work.

Under what we have called physical objects you will note that there are two categories. One category lists physical entities which have numerous examples that are easily perceived. Such concepts seem to present few problems providing that we are willing to take the time and effort to teach them. (That we do not always do this is clear to any teacher who has watched a student confuse a watch glass with an evaporating dish or crucible.) The other category lists names for physical entities which have no perceptible instances. Such concepts present problems and many students talk about atoms, molecules, and electrons at great length without understanding the concepts. Students who talk about atoms of salt and carbon dioxide are not simply being careless in their choice of words. I have encountered a number of students in a second semester chemistry course who did not distinguish atoms from molecules.

There are a number of chemical concepts which have perceptible instances but have defining attributes which are either imperceptible or perceptible only through indirect means. Several of these are listed under "class names

of physical objects". In some cases, certain examples of the concept have attributes which are easily perceived whereas other examples have the defining attributes concealed. Mixture is such an example. A handful of dirt is easily classified as a mixture because it has particles of macroscopic size which differ in properties. A solution of salt in water is not easily classified as a mixture because it is difficult to obtain evidence that different kinds of particles are present. Air represents an even more difficult case.

In developing a classification scheme for concepts, some are easily placed whereas others are not. For difficult cases it has sometimes been helpful to do a concept analysis. Concept analysis is a highly formalized procedure for looking at the meaning of a concept and sometimes leads to insight into why students find the concept difficult. The procedure consists of writing a definition, listing the defining attributes of the concept, listing irrelevant attributes that appear to be important in clarification of the concept, and giving examples and non-examples of the concept that would clarify both the relevant and irrelevant attributes. It may also be helpful to list supraordinate and subordinate concepts and principles which involve the concept under consideration.

There seems to be merit in collaboration on concept analyses. The concept analyses for "mole" and "mixture" which are given as an appendix to this paper were done as part of a recent seminar for graduate students in science education. Surprisingly, there was considerable disagreement concerning the definition of mole and the critical attributes of mole. Apparently the concept has lower validity than I had once thought. Still,

the most revealing part of the exercise came when we began to list examples and non-examples of mole. The first examples that came to mind were things like "16 g of oxygen" and "18 g of water." It was readily apparent that even though these are examples of a mole of substance, the only way for a person to know that they are examples is to apply a rule which relates the mass of substance to the number of particles contained in that mass. As it turns out, as long as we present examples such as those shown in Group I of the concept analysis, students have little difficulty in identifying a mole. The decision rule that is required is simple and already known to the student. However, when examples such as those given in Groups II, III, and IV are given, there are numerous errors.

Chemistry teachers generally report that the mole concept is one of the most difficult that they teach. But this really isn't true. The concept is of only moderate difficulty. The difficulty lies in the fact that there are a large number of decision rules that must be applied in order for a student to be able to classify all possible instances as examples or non-examples of the concept. Before being able to do the classifications that we so frequently require, the student must learn a large number of rules, he must be able to apply the rules correctly, and he must be able to select the correct rule for a given classification. Many examples require the successive application rules, and some of the rules involve abstract relationships which are difficult for students who have not developed formal thought. This was not apparent to us until we had done the concept analysis.

I have tried to suggest several things in the latter half of my paper that I consider important to college science teachers. First, since a number of college students are not formal thinkers and since much of the content of science appears to req[illegible] l thought, we must eith[illegible] ays to develop formal thought among these students or we must devise ways to circumvent the need for formal thought. Second, before we can even try to circumvent the need for formal thought, we must examine the concepts and principles that we teach in science to see what is involved in learning them. Third, I have suggested that a formal analysis of concepts can often lead to a better understanding of the logical problems inherent in learning the concepts. During the work session to follow our presentations I would like to work with some of you in doing concept analyses of some of the concepts that you find difficult to teach. It will be your chance to decide whether this kind of activity might lead to better science teaching.

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PHYSICAL ENTITIES

- Objects
  - Physical
    - Macroscopic
      - cathode ray tube
      - continuous spectrum
      - beaker
      - test tube
    - Microscopic
      - nucleus
      - alpha particle
      - atom
      - molecule
      - electron
      - proton
      - neutron
  - Representational
    - equation
    - symbol
    - formula
- Class names of physical objects
  - Directly perceptible
    - solid
    - liquid
    - gas
    - metal(macroscopic)
    - nonmetal(macroscopic)
    - substance
    - mixture (heterogenous)
  - Indirectly imperceptible
    - metal(micro)
    - nonmetal(micro)
    - alloy
    - acid
    - base
    - catalyst
    - mixture (homogenous)
    - element
    - compound
- Energy forms
  - wave
  - light
  - heat
  - energy
  - bond
- Standard measures
  - gram
  - coulomb
  - amu

Table 2. Classificatory scheme for objects.

Appendix A

Concept: Mole

Definition: A mole is the amount of substance of a system which contains as many elementary entities as there are carbon atoms in .012 kilograms of carbon-12. The elementary entity must be specified and may be an atom, a molecule, an ion, an electron, etc. or a specified group of such particles.

Critical Attributes:

1. mole refers to an amount of substance
2. a mole contains 6.02×10^{23} elementary entities
3. the elemental entity must be specified

Irrelevant Attributes:

1. amount of substance may be in terms of mass, number of particles, volume, or any other measure (However, the principle which allows one to determine the number of elementary entities in that amount of substance must be known.)

Supraordinate Concept: measures of amount of substance

Coordinate Concept: mass; number of particles, volume

Subordinate Concept: none

Group I

(In these examples, the student must apply certain rules of arithmetic but nothing more. They serve to focus on critical attributes 2 and 3.)

Examples	Non-examples
6.02×10^{23} cars (car)	6.02×10^{22} cars (car)
3.01×10^{23} bikes (wheel)	6.02×10^{23} bikes (wheel)
1.20×10^{21} reams of paper (sheet)	1.20 gross pencils (pencil)

Group II

(In these examples the student must apply a rule which relates the atomic mass of an element and the number of particles in that mass expressed in grams.)

Examples	Non-examples
16 g oxygen (O atom)	15 g oxygen (O atom)
14 g nitrogen (N atom)	28 g nitrogen (N atom)
35.5 g chlorine (Cl atom)	35.5 g chlorine (Cl_2 molecule)

Group III

(In these examples the student must apply rules which relate molecular weight to numbers of molecules.)

Examples	Non-examples
32 g oxygen (O_2 molecule)	16 g oxygen (O_2 molecule)
18 g water (H_2O molecule)	18 g water (atom)
9 g water (H atom)	9 g water (H_2O molecule)

Group IV (other rules)

Examples	Non-examples
2 g oxygen (electron)	2 g oxygen (O atom)
22.4 liters of gas at S.T.P. (gas particle)	22.4 liters of H_2 at STP (H atom)
1.0×10^{23} C^{12} (proton)	1.0×10^{23} C^{12} (nucleon)

Appendix B

CONCEPT ANALYSIS

CONCEPT: MIXTURE

DEFINITION: A mixture is an aggregate of two or more substances each of which retains its identity and specific properties.

Critical Attributes:

1. two or more substances or two or more phases of the same substance
2. each substance retains its identity

Irrelevant Attributes:

1. composition
2. mass
3. color
4. size of identifiable particles of each substance
5. number of components

Supraordinate Concept: Substance, Matter

Coordinate Concept: Pure Substance

Subordinate Concept: Homogeneous, Heterogeneous

Examples/Non-examples

In the following sets of examples, the student is presented with actual objects. The student is asked to distinguish between a mixture and a pure substance.

I.

Examples	Non-examples
cement	copper
brick	aluminum
dirt	iron
dimes and quarters	25 dimes
granite	diamond
milk	benzene (l)
air	oxygen (g)
gasoline	octane (l)
iron and sulfur	iron, sulfur
salt and pepper	salt, pepper
oil and water	oil, water
ice and water	ice
alcohol and water	methanol